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(54) Optical modulator.

(57) To provide an optical modulator which can perform optical modulation without using pulses having a high level peak power, a nonlinear optical medium (5) is disposed inside a laser resonator (1) which includes an input mirror (2), an output mirror (3), a laser medium (4) disposed between the input and output mirrors (2, 3), and exciting means (6) for exciting the laser medium (4) so that laser light is radiated by the laser medium (4). The optical modulator can operate in both self phase modulation mode (SPM) and induced phase modulation mode (IPM). To operate the optical modulator in SPM mode, the laser pulses passing through the nonlinear optical medium (5) are self phase modulated. To operate the optical modulator in IPM mode, a light emitting device (8) is provided which emits light to be modulated. The light to be modulated is incident on the input mirror (2) and passed through the medium (5) so that the light is induced phase modulated by the laser serving as a pumping light.

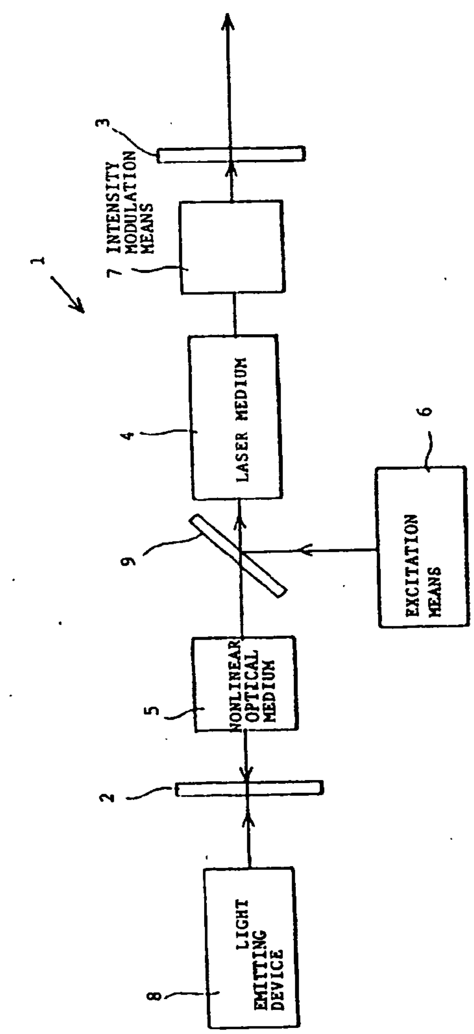

FIG. 1

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The present invention relates to an optical modulator wherein a light is modulated in a space within a laser resonator to attain the light modulation with good efficiency.

Intense, ultrafast, and broad-spectral-width pulses close to white-light called continuum or supercontinuum are generated by passing picosecond laser pulses through a nonlinear optical medium having a nonlinear refractive index.

For spectral broadening, it has been known to utilize a phase modulation wherein the spectral range of the laser is broadened when the laser pulse passes through a nonlinear optical medium. As the laser pulse passes through the medium, it causes a refractive index change. This in turn induces a phase change which causes a frequency sweep within the pulse envelop. This process is called self phase modulation (SPM). There are other processes known as induce phase modulation (IPM) and cross phase modulation (XPM). In IPM, a phase modulation for the laser pulses are performed by the aid of an intense laser pulse serving as pumping light. More specifically, when a weak pulse of a different frequency passes through the medium whose refractive index was changed by an intense laser pulse, the phase of the weak optical field an be modulated by the time variation of the index of refraction originating from the primary intense pulse. In XPM, stimulated Raman scattering, harmonic generation and four photon parametric generation induced by an excited light pulse generate a light whose wavelength is different from the wavelength of the excited light, resulting in generation of a spectrally broadened light having a spectrum around the frequency of the excited light. Through the use of such processes, the spectrum of the laser pulse can be broadened.

According to SPM, an amount of phase modulation is dependent on light intensity of the incident light, so that it is necessary to introduce a large peak power laser to effectively broaden the spectrum. According to IMP or XPM, while it is not required that the light to be modulated be of a large peak power, it is necessary that the pumping light be of a large peak power. There is a problem that a high modulation efficiency is not attainable in an optical modulation utilizing a nonlinear effect, because the modulation efficiency is dependent on the peak power of the light.

According to a first aspect of this invention an optical modulator comprising a laser resonator having a first mirror, a second mirror, a laser medium disposed between the first and second mirrors, and exciting means for exciting the laser medium so that laser light is radiated by the laser medium;

is characterised by

at least one nonlinear refractive index medium disposed inside of the laser resonator for modulating light output from the resonator.

According to a second aspect of this invention an optical modulator comprising a semiconductor laser having an active semiconductor layer, and exciting means for exciting the active semiconductor layer so that laser light is radiated by the active semiconductor layer;

is characterised by

a nonlinear refractive index medium partially formed in the active semiconductor layer for modulating the light.

The optical modulator can operate in both self phase modulation mode and induced phase modulation mode. To operate the optical modulator in the self phase modulation mode, the laser pulses passing through the nonlinear refractive index medium are self phase modulated. To operate the optical modulator in the induced phase modulation mode, a light emitting device is provided which emits a light to be modulated. The light to be modulated is incident on the input mirror and passed through the medium so that the light is subjected to induced phase modulation by the laser serving as a pumping light.

Laser power in the interior of the laser resonator is much stronger than the power of the laser derived outwardly of the laser resonator. Therefore, the light is effectively modulated by the nonlinear medium disposed interiorly of the laser resonator.

For the plurality of nonlinear media, non-selected nonlinear media are used to achieve different purposes. For example, an intensity modulation or high harmonic generations are accomplished by applying an electric filed thereto to change the reflective index.

The present invention will be better understood from the following description, given by way of example with reference to the accompanying drawings in which:

Fig. 1 is an explanatory diagram showing an optical modulator according to a first embodiment of the present invention;

Fig. 2 is an explanatory diagram showing an optical modulator according to a second embodiment of the present invention;

Fig. 3 is an explanatory diagram showing an optical modulator according to a third embodiment of the present invention;

Fig. 4 is a perspective view showing a masked nonlinear medium for the third embodiment of the present invention; and

Fig. 5 is an explanatory diagram showing an optical modulator according to a fourth embodiment of the present invention.

A first embodiment of the present invention will be described with reference to Fig. 1.

A laser resonator 1 is basically made up of an input mirror 2, an output mirror 3, a laser medium 4, and an excitation means 6 for exciting the laser medium 4. A nonlinear optical medium 5 whose refractive index changes when laser pulses pass therethrough is disposed interiorly of the laser resonator 1

on the longitudinal axis thereof. An intensity modulation means 7 may optionally be disposed interiorly of the laser resonator 1. With such an arrangement, the light to be modulated is subjected to light modulation with the nonlinear optical medium 5 disposed inside the laser resonator 1, to thereby broaden the spectrum.

The input mirror 2 allows to pass the light to be modulated therethrough but rejects the transmission of the laser light oscillating in the laser resonator 1. The output mirror 3 allows the modulated light to pass therethrough but rejects the transmission of the laser tight oscillating in the laser resonator 1.

Semiconductor, solid, liquid and gaseous materials are usable for the laser medium 4. Typically, semiconductor materials, such as GaAs, InGaAsP, InAlP, solid materials, such as Nd-YAG, YLF, $Cr^{3}+:Mg_2SiO_4$, $Cr^{4}+:Mg_2SiO_4$, and fibers, liquid materials, such as Rhodamine6G, gases materials, such as argon, excimer, CO_2, copper vapor, are used.

The excitation means 6 is a light source which excites the laser medium 4. Discharge excitation, current excitation, or chemical reaction excitation are available for the excitation means 6, which are selected depending upon the materials of the laser medium 4 used. An optical excitation will be taken as an example in the following description.

In the illustrated embodiment, a dichroic mirror 9 is arranged for introducing a pumping light in parallel to an optical axis. The dichroic mirror 9 has a high reflectivity against the exciter laser wavelength and a high transmissivity for the wavelength of the light to be modulated. It is to be noted that the dichroic mirror 9 can be dispensed with when the pumping light is incident in a direction orthogonal to the optical axis.

The nonlinear optical medium 5 is selected from the materials having a nonlinear refractive index. Such materials include, for example, hydrogen, water (H_2O, D_2O), acetone, cyclohexanone, nitrogen, oxygen, nitrobenzene, toluene, chlorobenzene, bromobenzene, benzene, CS_2, CCl_4, diamond, calcite, silicon, rock crystal, $LiTaO_3$, $LiNbO_3$, and InSb.

The intensity modulation means 7 can be selected from a Q-switch, cavity dumper, mode locker, and passive mode locking owing to a saturable absorption dye. For the laser medium 4 made of a semiconductor material, the intensity modulation means 7 can be dispensed with by using a pulsating excitation current.

For the Q-switch constituted with an A/O element or E/O element, the laser medium 4 is excited under the condition where the Q level is lowered, and then the Q locking is abruptly increased when the reverse distribution density has become sufficiently large, to thereby obtain an intense, ultrashort duration laser output.

For the cavity dumper used for the intensity modulation means 7, the laser output is pulsated while instantaneously taking out the energy stored in the interior of the laser resonator 1 through diffraction.

For the mode locker used for the intensity modulation means 7, an A/O element or E/O element is incorporated in the interior of the laser resonator 1 to forcibly synchronize the phases of a plurality of simultaneously oscillating longitudinal modes using an electrical signal applied from externally.

When the intensity modulation means 7 is operating in the passive mode synchronization by the use of an absorbable dye, the absorbable dye absorbs the weak light to thereby further weaken the light but little absorbs the intense light and keeps such light substantially the same.

It should be noted that the excitation means 6 can double as the intensity modulation means 7. Specifically, in the case of light excitation, the excitation means 6 pulsates the excited light, and in the case of current excitation, the excitation is performed by a pulsating current. A hybrid arrangement in which these excitation means 6 are combined can be adopted.

The optical modulator 1 shown in Fig. 1 can operate in both self phase modulation mode and induced phase modulation mode. To operate the optical modulator 1 in the self phase modulation mode, the oscillated laser pulses passing through the nonlinear optical medium 5 are self phase modulated. In this case, the output mirror 3 partially passes the oscillated laser wavelength to derive the output therefrom.

To operate the optical modulator in the induced phase modulation mode, a light emitting device 8 is provided which emits a light to be modulated. The light to be modulated is incident on the input mirror 2 and passed through the medium 5 so that the light is subject to induced phase modulation by the laser serving as a pumping light.

More specifically, the laser medium 4 of the laser resonator 1 is excited by the excitation light from the excitation means 6 and a pulse oscillation occurs by virtue of the intensity modulation means 7 disposed within the laser resonator 1. Under the condition that the pulse oscillation is taking place in the laser resonator 1, the light emitted from the light emitting device 8 is applied to the input mirror 2. In the interior of the nonlinear optical medium 5, the refractive index changes when the laser pulses oscillating in the laser resonator 1 pass therethrough. Accordingly, when the laser pulses and the light to be modulated are superposedly propagating through the nonlinear optical medium 5, the light to be modulated is subjected to phase modulation and the phase modulated light, i.e., frequency broadened light, is derived from the output mirror 3.

In the arrangement shown in Fig. 1, with the provision of a wavelength dispersion correcting mechanism, such as grating pair, in the interior of the laser resonator 1, the peak power of the laser pulse oscillating in the laser resonator 1 can be increased, whereby modulation efficiency can be improved and

the modulated light can be formed into a ultrashort pulsation. Further, it is possible to vary the pulse duration.

A second embodiment of the present invention will be described with reference to Fig. 2.

Fig. 2 shows an arrangement of an optical modulator in the form of a semiconductor laser, in which a nonlinear optical region 5 having a nonlinear refractive index is partially formed in an active layer 12. Both sides of the optical modulator are formed with coatings 10a, 10b by evaporation, which coatings have a high reflectivity against the oscillating wavelength of the semiconductor laser but have a high transmissivity for the wavelength of the light to be modulated.

In this arrangement, when the semiconductor laser is driven with a short duration pulses, a pulse oscillation occurs in the laser resonator 1. A light to be modulated is incident on the optical modulator from a light emitting device 8 as shown in Fig. 1 through the coating 10a, the light is subjected to phase modulation in the nonlinear optical region 5, whereby modulated light is derived outwardly from the coating 10b.

In the second embodiment, current pulses generated when a high frequency current is applied to a comb generator can be used as a current source for exciting the semiconductor laser. While in the illustrated embodiment, the coatings 10a, 10b are evaporated on the side surfaces of the optical modulator, the arrangement can be modified so that the side surfaces are coated with non-reflective coatings and input and output mirrors are disposed outside of the semiconductor laser as in the first embodiment.

A third embodiment of the present invention will be described with reference to Figs. 3 and 4.

The arrangement shown in Fig. 3 is substantially the same as that shown in Fig. 1. However, in the arrangement of Fig. 3, both sides of the nonlinear optical medium 5a are formed with masks 13a, 13b which form a prism-shaped laser transmissive region as shown in Fig. 4.

In this arrangement, oscillation takes place in the interior of the laser resonator 1 similar to the first embodiment shown in Fig. 1. The third embodiment differs from the first embodiment in that with the provision of the masks 13a, 13b on both sides of the nonlinear optical medium 5a, the cross-sectional pattern of the laser oscillating in the interior of the laser resonator 1 is in the form of prism.

If a light to be modulated is incident on the medium 5a from the surface A indicated in Fig. 4, that is, from the surface of the nonlinear optical medium 5a intersecting the optical axis of the laser resonator 1, the reflective index of the prism-shaped region of the nonlinear optical medium 5a changes only when the laser pulses propagate through the medium 5, so that the light modulation can be achieved in synchronism with the laser pulses oscillating in the laser resonator 1.

In the third embodiment, the masks 13a, 13b may not be prism-shaped but can be configured to various shapes. By configuring the masks 13a, 13b into a lens shape, convergence of the modulated light can be achieved in synchronism with the laser pulses. Further, the positions of the non-linear medium 5a having the masks 13a, 13b are not limited to those illustrated in Fig. 3 but may be positioned anywhere in the interior of the laser resonator 1.

Fig. 5 shows a modification of the optical modulator wherein a second harmonic generator (SHG), a third harmonic generator (THG), a fourth harmonic generator (FHG), and a wavelength converting device 11, such as a parametric wavelength converter, are provided in the interior of the laser resonator 1.

In the arrangements of Figs. 1 and 5, modifications can be made so as to provide a wavelength selection device either internally or externally of the laser resonator 1. With such an arrangement, the wavelength can be converted to fall in an extensive range. Further, in the foregoing embodiments, a plurality of nonlinear optical media may be provided.

With the present invention arranged as described above, the light to be modulated and the pumping light are not required to be of a large power peak, yet enabling to modulate the light with good efficiency. When the optical modulator is operated in IPM or XPM, it is advantageous in that the wavelength of the light can be varied to fall in a desired range by selecting the wavelength of the light as desired.

Claims

1. An optical modulator for modulating light, comprising:

   a laser resonator (1) having a first mirror (2), a second mirror (3), a laser medium (4) disposed between the first (2) and second (3) mirrors, and exciting means (6) for exciting the laser medium (4) so that laser light is radiated by the laser medium;

   characterised by

   at least one nonlinear refractive index medium (5) disposed inside of the laser resonator (1) for modulating light output from the resonator (1).

2. An optical modulator according to claim 1, wherein the exciting means (6) excites the laser medium so as to radiate pulses of laser radiation.

3. An optical modulator according to claim 2, wherein said nonlinear refractive index medium (5) is arranged so that the laser pulses pass through it, thereby self phase modulating the laser pulses.

4. An optical modulator according to any one of the

preceding claims, further comprising intensity modulating means (7) disposed inside the laser resonator (1) for intensity modulating the laser.

5. An optical modulator according to any one of the preceding claims, wherein said nonlinear refractive index medium (5) has two opposing surfaces on which masks (13a,13b) are partially formed to thereby form a region in the nonlinear refractive index medium (5) through which the laser light passes.

6. An optical modulator according to any one of the preceding claims, further comprising a second harmonic generator (SHG), a third harmonic generator (THG), a fourth harmonic generator (FHG), or a wavelength converting device (11).

7. An optical modulator for modulating a light, comprising:

a semiconductor laser having an active semiconductor layer (12), and exciting means for exciting the active semiconductor layer so that laser light is radiated by the active semiconductor layer (12);

characterised by

a nonlinear refractive index medium (5) partially formed in the active semiconductor layer (12) for modulating the light.

8. An optical modulator according to claim 7, wherein the semiconductor laser has two opposing surfaces on which coatings (10a,10b) are formed, the coatings (10a,10b) reflecting the laser light.

9. An optical modulator according to any one of the preceding claims, further comprising light emitting means (8) for emitting a light to be modulated, the light being incident on and transmitted by first mirror (2) and or coating (10a) and passing through the nonlinear refractive index medium (5) so that the light is subjected to induced phase modulation by the laser light.

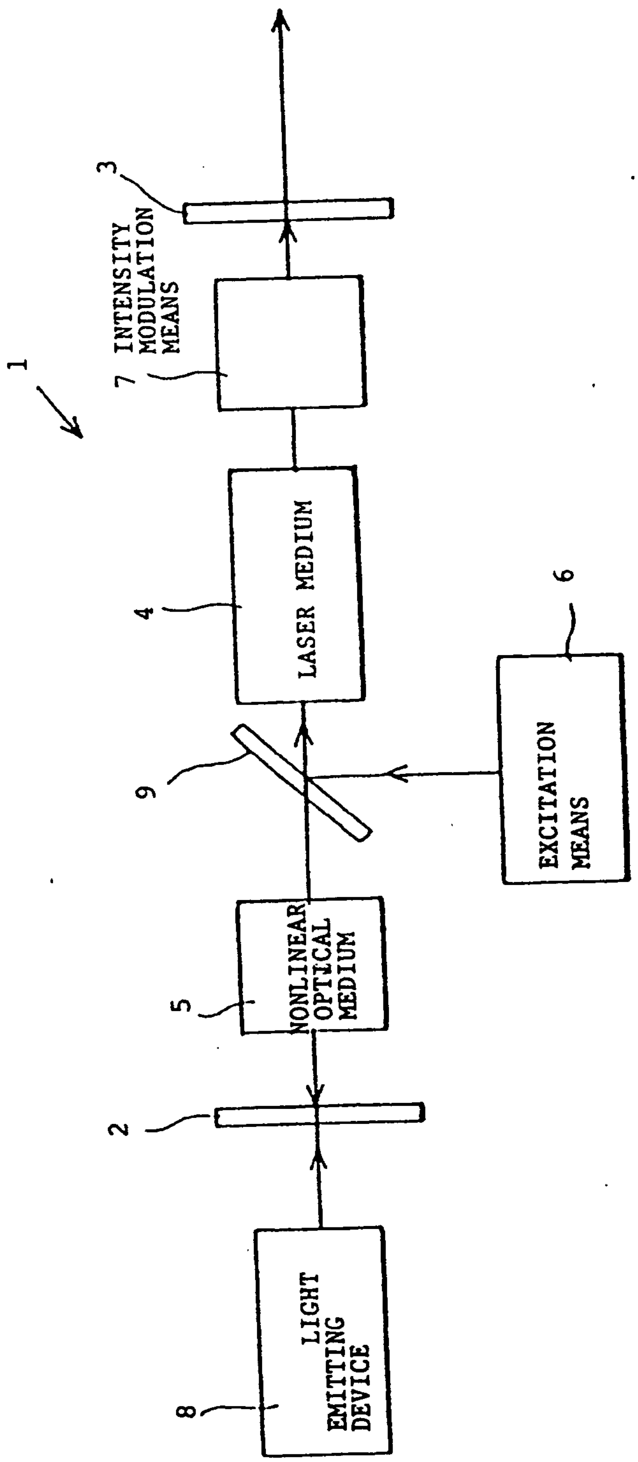

1
3
7 INTENSITY MODULATION MEANS
4
LASER MEDIUM
6
EXCITATION MEANS
9
5
NONLINEAR OPTICAL MEDIUM
2
8
LIGHT EMITTING DEVICE

FIG. 1

FIG. 2

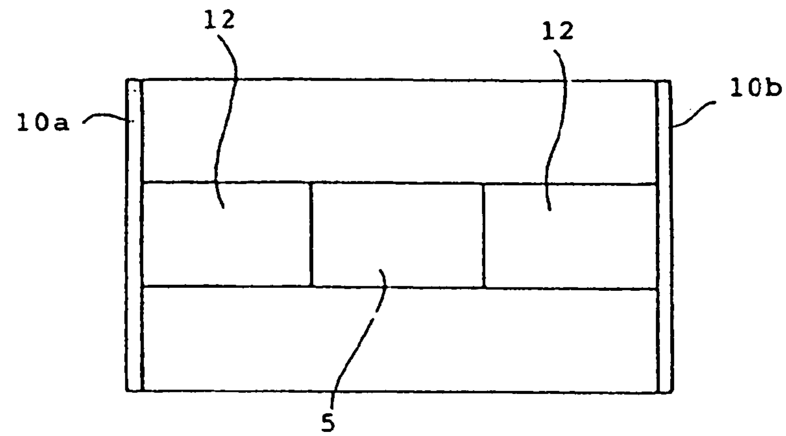


FIG. 3

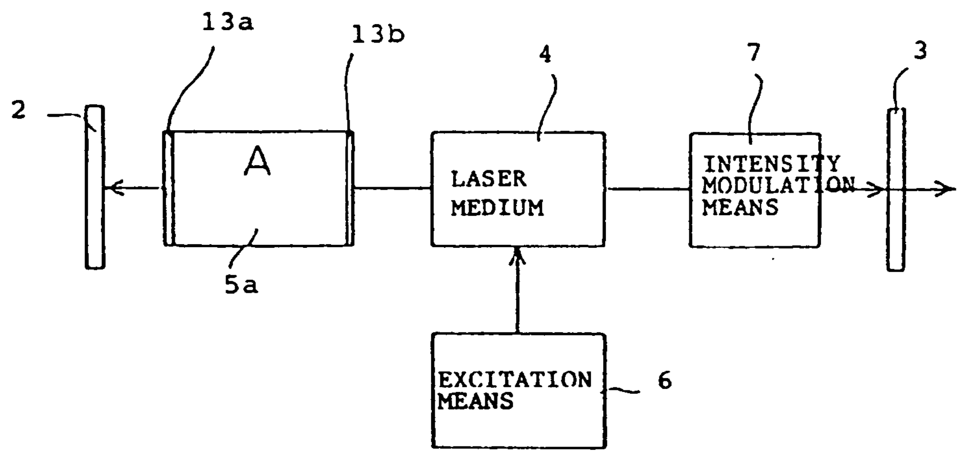


FIG. 4

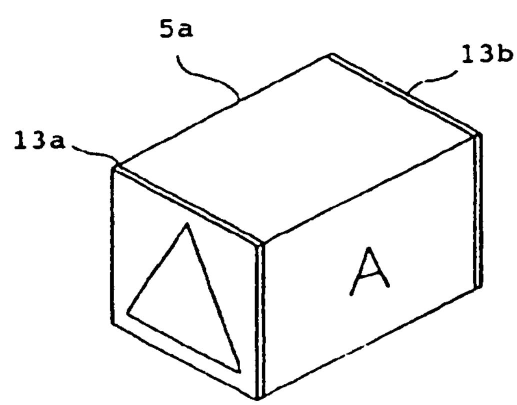
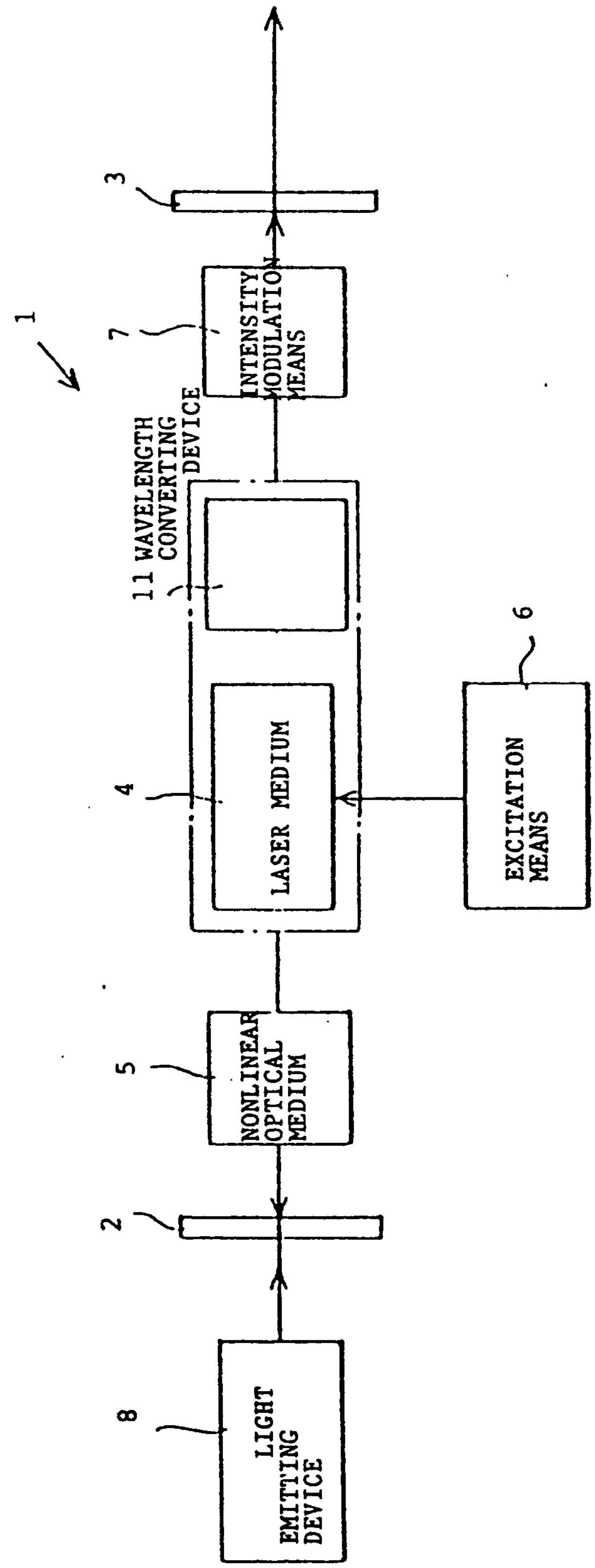


FIG. 5


1
LIGHT EMITTING DEVICE
8
2
NONLINEAR OPTICAL MEDIUM
5
LASER MEDIUM
4
EXCITATION MEANS
6
11 WAVELENGTH CONVERTING DEVICE
INTENSITY MODULATION MEANS
7
3

European Patent Office

EUROPEAN SEARCH REPORT

Application Number EP 92300609.2

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
X	US - A - 4 884 277 (ANTHON et al.)	1	H 01 S 3/108
A	* Column 4, lines 57-65; fig. 1,3,4 * --	2,3,6	
X	US - A - 4 791 631 (BAUMERT et al.)	1	
A	* Column 2, lines 22-60; fig. 1,2 * --	2,3,9	
A	FR - A - 2 553 204 (CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE) * Abstract; page 3, lines 19 - page 6, line 11 * --	1,2	
A	US - A - 4 588 957 (BALANT et al.) * Column 1, line 58 - column 2, line 29; column 3, line 13 - column 6, line 6 * --	1,3	TECHNICAL FIELDS SEARCHED (Int. Cl.5)
A	WO - A - 85/00 472 (ATRT) * Abstract; fig. 1 * --	7,8	H 01 S 3/00 G 02 F 1/00
A	WO - A - 90/02 429 (THE REGENTS OF THE UNIVERSITY OF CALIFORNIA) * Abstract; fig. 5 * ----	7	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
VIENNA	08-05-1992	GRONAU

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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